MICROWAVE MEASUREMENT OF SNOW WETNESS ACCUMULATION

William I. Linlor, NASA-Ames Research Center
Diogenes Angelakos, University of California
Fred Clapp, University of California

INTRODUCTION

This report describes work performed under the Consortium Agreement No. NCA2-OR050-006, between NASA-Ames Research Center and the University of California, Berkeley.

BACKGROUND

The water stored in mountain snowpacks is an important resource. The amount of stored water is evaluated by snow-course measurements, supplemented by data from pressure pillows and the Smith density-profiling instruments. For efficient management of water resources, information must be obtained regarding the timing of snowpack melt and related water discharge rates. Measurement of snow wetness accumulation during the melt season would permit more accurate prediction of the water runoff time and rate.

The research described in the report is the outgrowth of a prior interchange (NCA2-OR050-704). Results obtained have furnished the basis for selection of frequency range, deployment height of microwave horns, and sampling cycles necessary to obtain data suitable for the calculation of snow wetness accumulation. Results have been presented in the paper "Snow Electromagnetic Measurements," by Linlor, Smith, Clapp, and Angelakos, published in the NASA Publication 2153, May 1980.

APPROACH

Three microwave horns were placed at ground level, directed vertically, as shown in the attached photographs, Fig. 1. The horns were enclosed in water-proof containers having plexiglas plates to protect the horns from the expected weight of the snow. A companion set of horns was mounted on a beam, spaced so that corresponding units were aligned vertically. The frequency ranges of the horns are:

Set A: 1.0 to 2.4 GHz

Set B: 2.0 to 5.0 GHz

Set C: 4.0 to 8.4 GHz

Crystal detectors were attached to the horns within the enclosures, and coaxial cables were run to an adjacent instrument hut.

This arrangement was intended to permit measurement of the attenuation of microwave signals that are transmitted <u>vertically</u> through the snowpack, under dry and wet conditions.

A second set of microwave horns was deployed so as to measure the attenuation of signals that are transmitted <u>horizontally</u> through the snowpack, at various heights above the earth. The arrangement of these horns is shown in the attached photographs, Fig. 2. Pairs of horns were supported by aluminum beams at the heights of 2, 4, 6, and 8 feet. A "redundant" set of horns was placed at the 4-foot level, to provide a check on the performance, making a total of five sets of horns. Each set operated in the frequency range of 4.0 to 8.0 GHz. A coaxial switch permitted the connection of "transmitter" horns to a sweeper, in succession.

Another coaxial switch connected the corresponding "receiver" horn to a crystal detector. A coaxial cable having 30 dB attenuation was employed to provide confirmation that the system was functioning properly.

Measurements were taken by Central Sierra Snow Laboratory personnel each morning and evening, using the five sets of horns plus the cable having the attenuater. As a part of their Forest Service measurements, the personnel recorded many meteorological quantities such as rain or snow fall; temperature of the ground, snowpack, and air; solar irradiance, etc.

The instrumentation of the Forest Service and the present experiment provided measurements of the snowpack that can be correlated with ambient conditions. The question of particular interest, which in the past has not been answered is---for an undisturbed snowpack that has reached a condition of maximum wetness via snowmelt, what is the average wetness? The present experiment has provided the answer for the representative snowpack of the 1981-82 winter.

MEASUREMENTS

Calibration runs were taken on Sept. 23, 1981, prior to the start of the snow season. Figure 3 shows the response of the vertically-aligned horns operating between 1.0 and 2.4 GHz, for three face-to-face horn separations (33, 66 and 96 inches), employing the constant (i.e., levelled) sweeper output power of +13 dBm. Some variation in the received signal is observed as a function of frequency;

the average signal is approximately 39 dB for the separation of 96 inches of the horn faces.

Figure 4 shows the XY plots of the responses of the remaining two sets of horns (2.0 to 5.0 GHz and 4.0 to 8.4 GHz respectively), for the three face-to-face horn seprations of 33, 66, and 96 inches. Variations in the received signals are evident, as usual in such measurements. The averaged signals are shown by the straight lines for each set of horn separations.

The air calibration data are summarized in Table I.

Dry Snow

When the snow season began, the Snow Laboratory personnel cleared off the tops of the horns and compacted the snow around the horn enclosures, up to the level of the plexiglas plate (all three horn enclosures plus plexiglas plate had the same height), so that no "bulge" could be produced by the presence of the horns. After this level was reached, no subsequent disturbance of the snowpack was allowed, particularly with regard to compaction of the snow by personnel walking over it.

The snowpack reached an average depth of 106 inches on January 22, 1982. The surface was not parallel to the earth, but had a height of 99 inches at one end of the beam supporting the horns, and a height of 112 inches at the other end. The top of the plexiglas plate, having a height of 24 inches, is subtracted from the average snow height to yield the separation of the horn faces of 82 inches.

Data obtained on January 22, 1982 are shown in Fig. 5. A malfunction for "Sweeper B" required operation in the non-levelled mode from 1.0 to 2.4 GHz. However, an overlap with "Sweeper A" in the vicinity of 2.4 GHz, provided the measurement of the average signal power of 43 dB from 1.0 to 2.4 GHz, as shown in TABLE II. (The cross-hatched portion of the curves in Fig. 5 should be disregarded, because the microwave horn was out of design range above 2.4 GHz.)

Figure 5 gives the signal strength in the frequency range of 2.0 to 7.0 GHz, having the average values shown in TABLE II. The drop in signal above 7.0 GHz shows that the snow is beginning to produce attenuation, but the region above 7.0 GHz is not used in subsequent measurements with wet snow.

Comparison of the results of TABLES I and II shows that the presence of the snow <u>increases</u> the signal of the receiver horns. This implies two effects: first, the snow is sufficiently dry so that negligible attenuation is present up to about 7.0 GHz; and second, the microwave power radiated by the horns immersed in the snowpack is re-directed toward the horn axis, thus increasing the power in that direction. Compared to the air response, the signal for the case of dry snow shows an increase of about 3 dB for the horns of Set A; about 5 dB for Set B; and about 10 dB for Set C.

The signal strengths of TABLE II are taken as the reference values, rather than TABLE I, to obtain the attenuation of wet snow, as is described in the next section. The effect of horn separation is assumed to given in dB by the quantity 20 log (a/b) where a and b represent respective separations.

Wet Snow

The snowpack had a depth of 86 inches on May 11, 1982, when measurements were taken; the separation between horn surfaces was 62 inches. At this date the snowpack was "ripe" meaning that meltwater had thoroughly penetrated the snow, and was draining off.

Figure 6 shows the XY plots for the frequency range of 1.0 to 2.4 GHz, the sweeper being levelled at 13 dBm; and the frequency range of 2.0 to 4.5 GHz, the sweeper being levelled at 16 dBm. The straight lines drawn through the XY plots represent averaged values.

RESULTS

The results of the measurements are given in TABLES I, II, and III.

TABLE I shows the signal received for the calibration runs in air, for the horn-face separation of 96 inches.

TABLE II shows that the signal received (with the effect of horn separation being taken into account) increases, compared to the value of TABLE I. As explained above, this effect is caused by the re-direction of the radiated power because of the dielectric constant of the snow at the horn termination. The values of TABLE II are employed in the following TABLE III, to yield the attenuation.

TABLE III shows the received signal at selected frequencies in the range of 1.0 to 5.0 GHz. The attenuation is given by the "dry-snow signal" minus the "wet-snow signal" which is shown in the "delta-dB" column. Dividing this by the path length of 157.5 cm (i. e., 62 inches), yields the column labelled "dB/cm".

CONCLUSIONS

The major conclusion of this investigation is that the microwave method for measuring snowpack wetness is practical and accurate.

The comment must be made that an important portion of the investigation could not be completed because of the fact that NASA management terminated the project as of December 31, 1981. For this reason the Ames collaborator (WIL) could not officially visit the Snow Lab during 1982 to acquire data and to verify that the instrumentation was functioning properly.

The Ames collaborator visited the Snow Lab in January and May of 1982 at his own expense, using vacation time.

However, it was not practical to continue with the measurements using the horizontal pairs of horns, at the various heights above ground, to obtain time-dependent variation of snowpack wetness.

The attenuation in dB/cm versus frequency is plotted in Fig. 7. Two different relations are shown by the solid and the dashed lines. These lines should have equal height and slope at the same frequency. The disparity is attributed to the difference in horn characteristics and the matching to the snow impedance.

The attenuation of 0.27 dB/cm at 4.0 GHz is taken to represent the average snowpack value. This is employed in the relation, equation (5) published in Journal of Applied Physics, May 1980, page 2813, (Linlor, "Permittivity and attenuation of wet snow between 4 and 12 GHz"):

$$dB/cm = W_v(0.045(f-4) + 0.066)$$

where f is the frequency in Ghz

W_v is the volume percent wetness

The value of volume percent wetness is calculated to be 4.1 percent. This is the average value for the total snowpack.

The density of the snowpack was measured by Snow Laboratory personnel with the Smith profiling gauge each day during the snow season. The average value of the snowpack density on May 11, 1982 was 0.41 grams per cubic centimeter. Using this value, together with the volume percent wetness of 4.1 percent, one obtains the wetness of 10 percent by weight. This represents a large fraction of the mass of the snowpack.

These results provide a reasonably reliable value for snowpack wetness. However, it must be stressed that a suitable statistical sample of snowpacks should be measured, to determine the range of values, and that these must be correlated with the prevailing meteorological conditions, in order to arrive at definitive values for snowpack wetness.

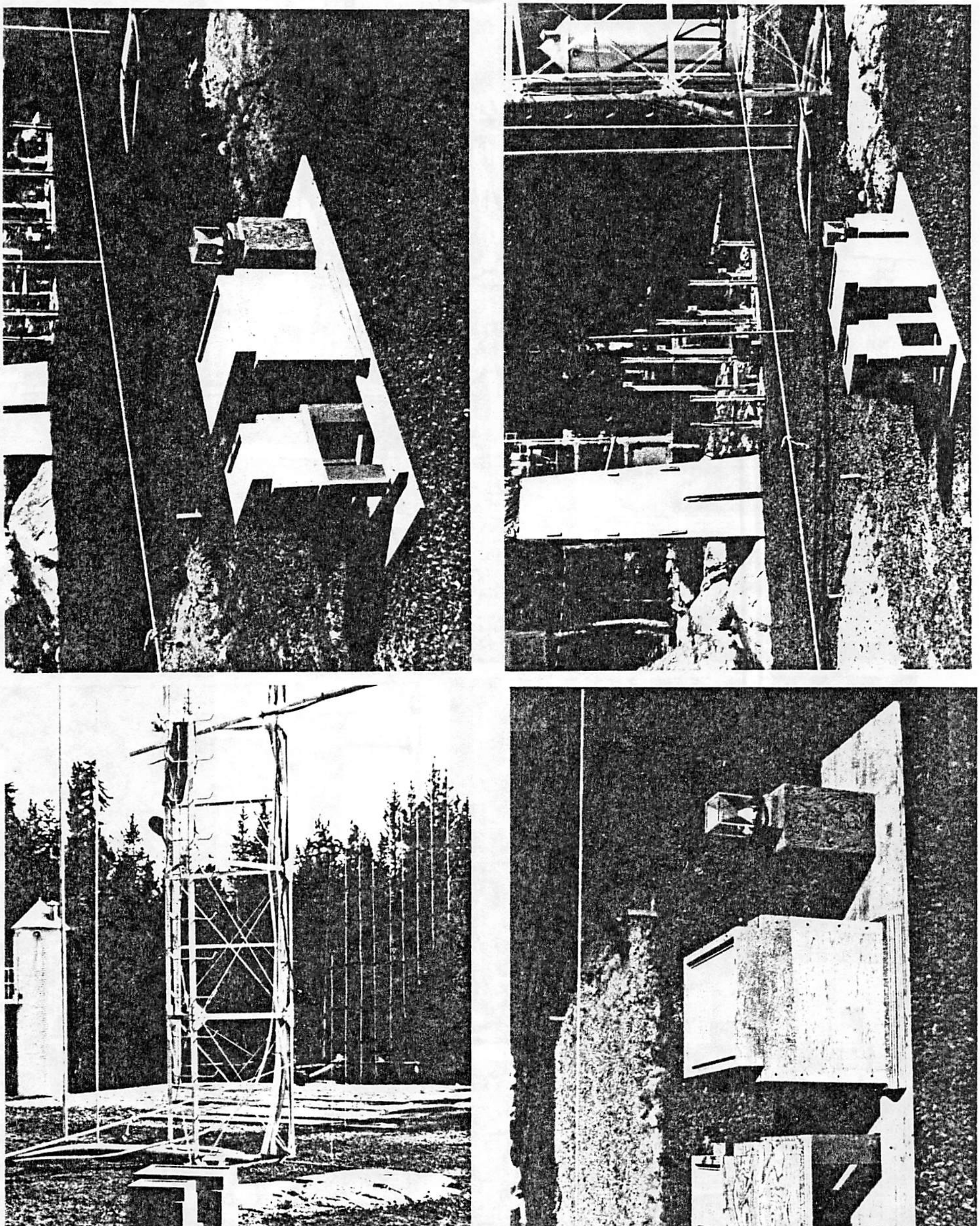


FIG. 1

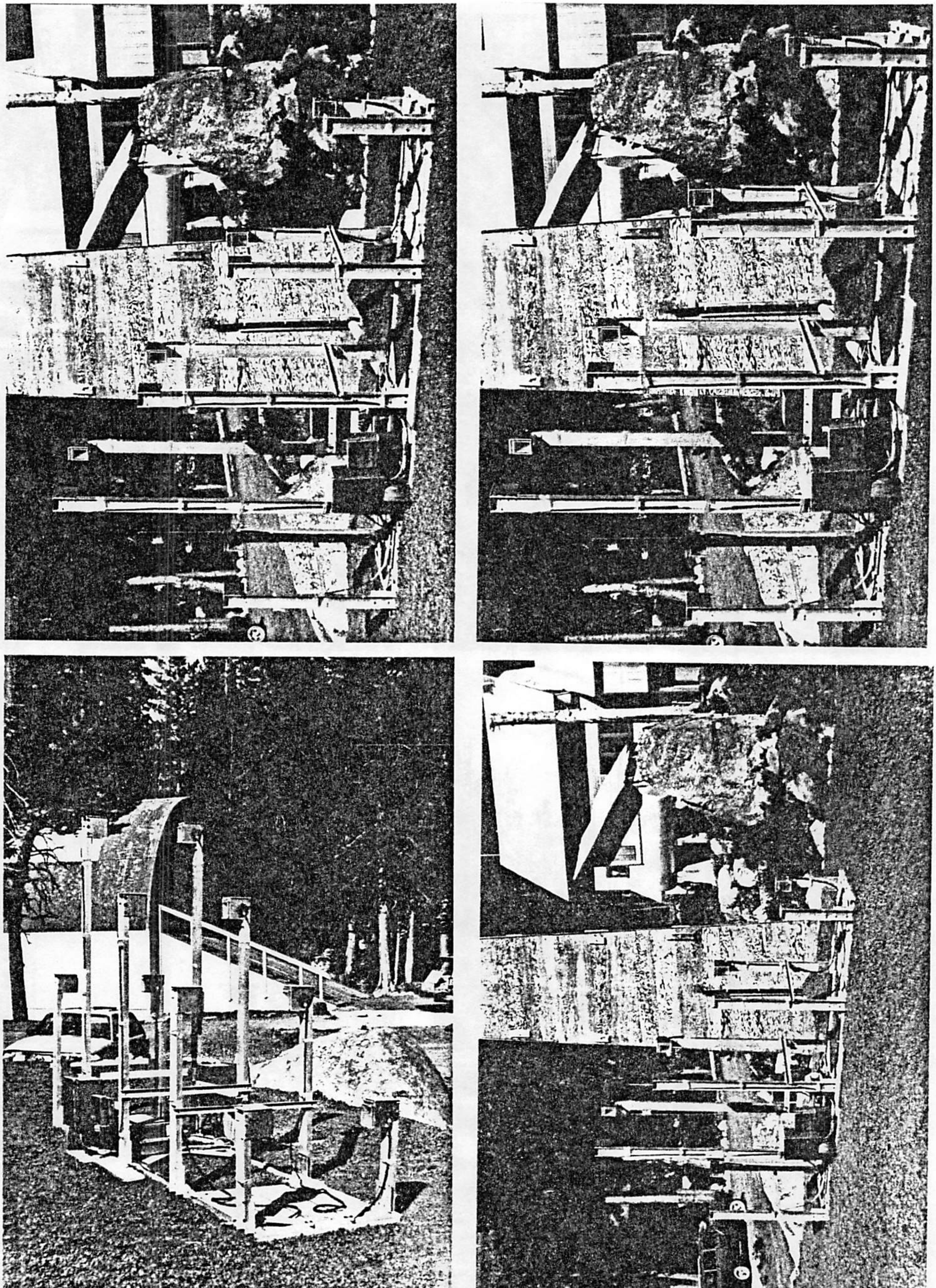


FIG. 2

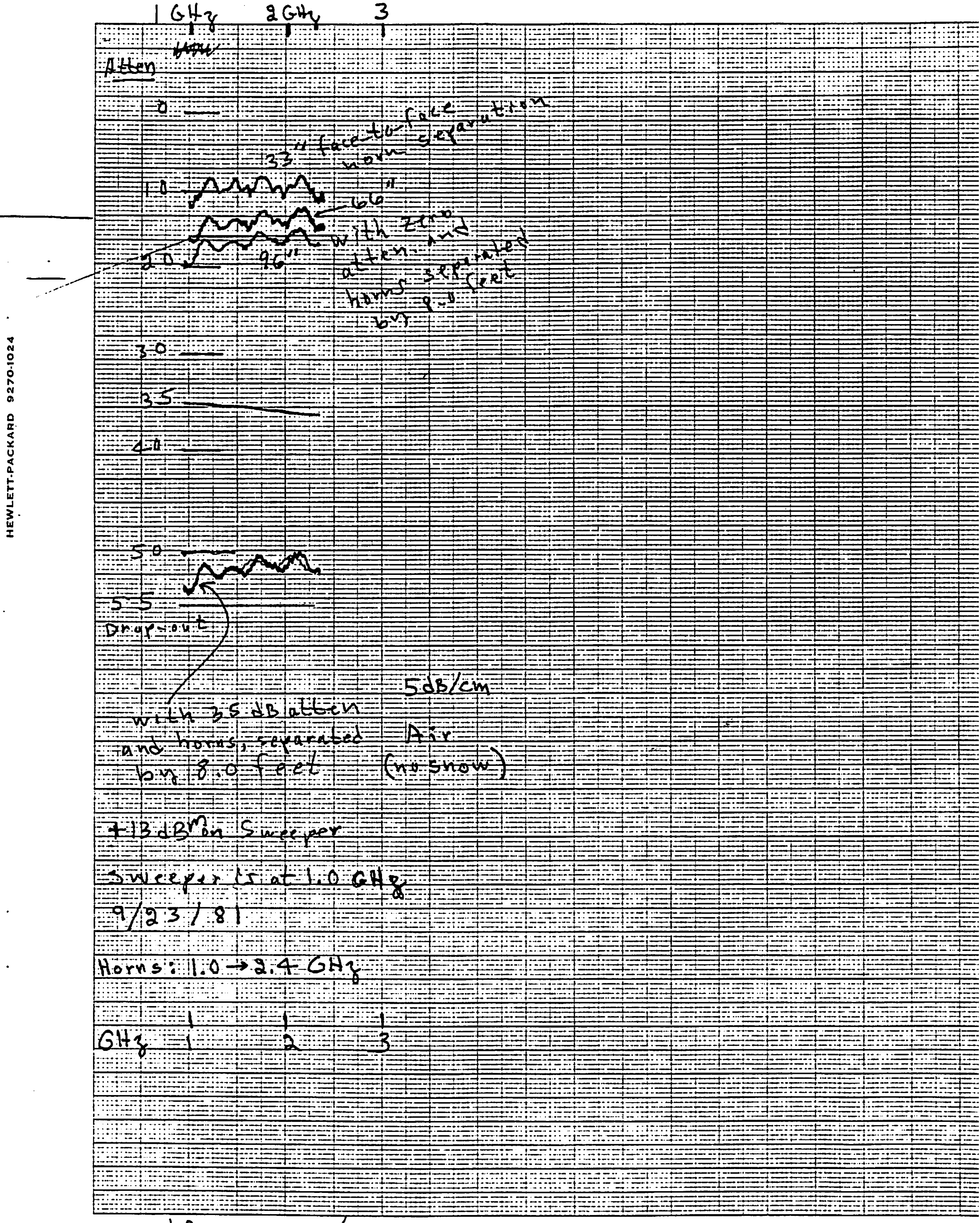
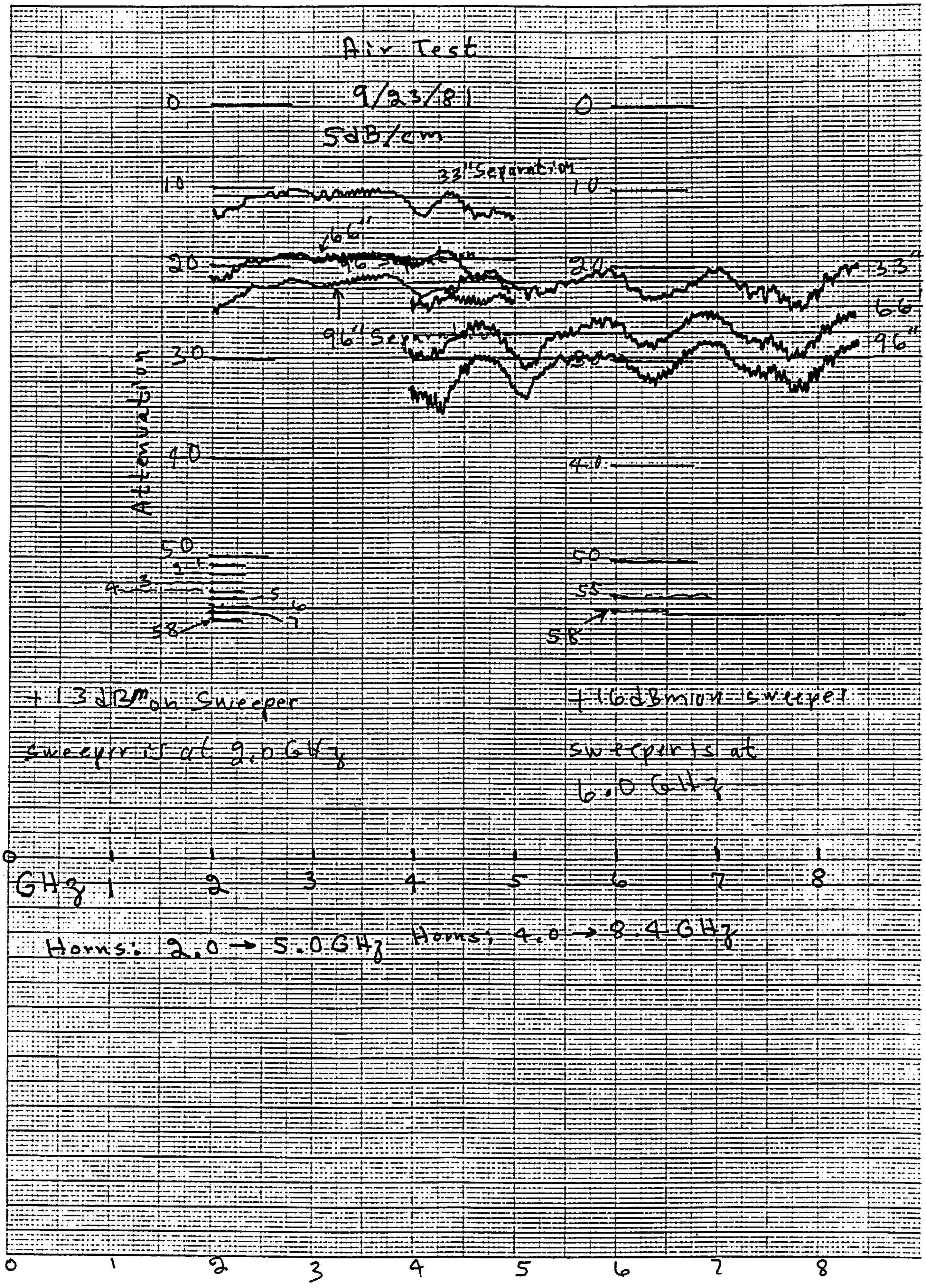
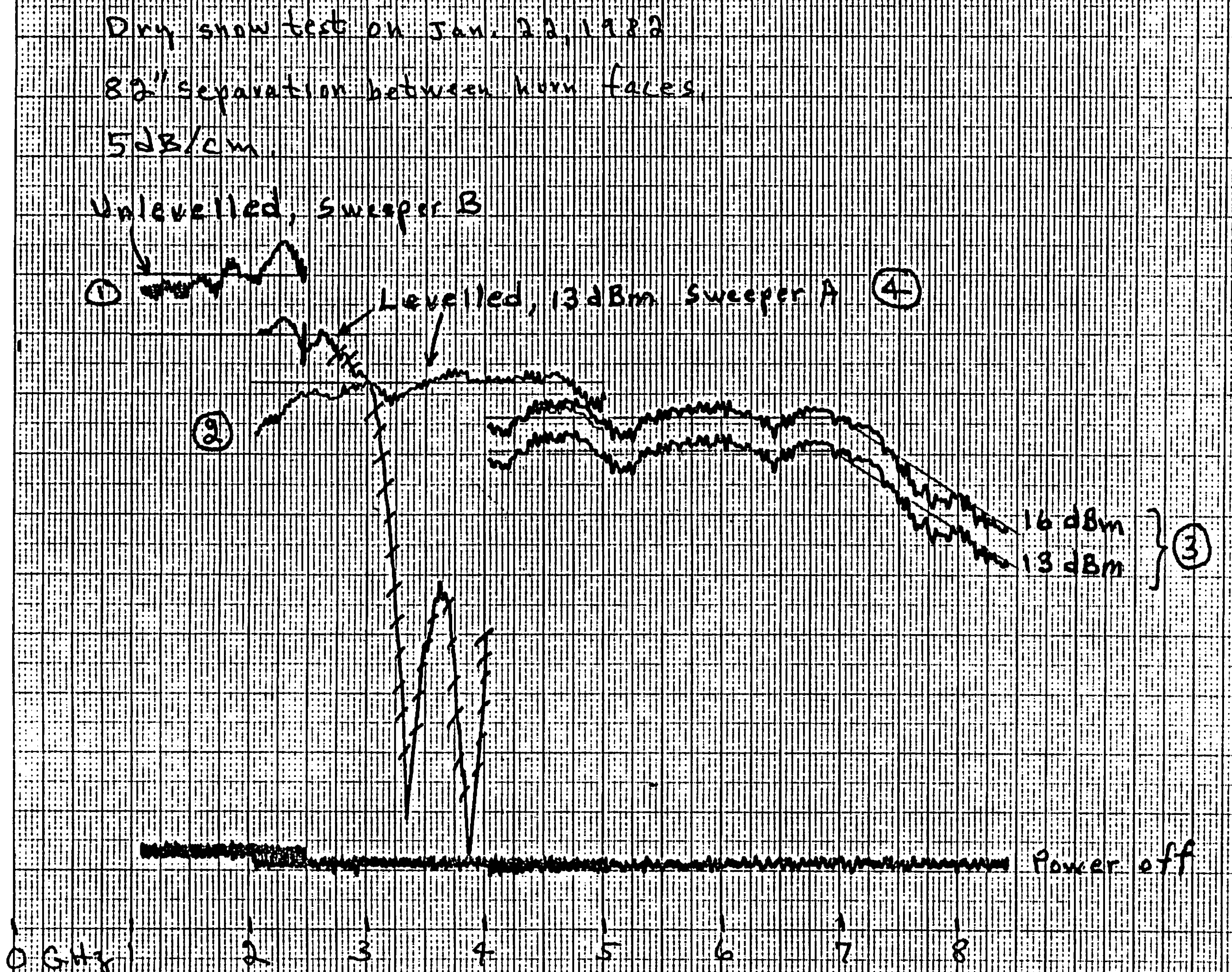

1 GHz
2 GHz
3
Atten
0
10
20
30
35
40
50
55
33" face-to-face horn separation
66"
96"
with zero atten and horns separated by 8.0 feet
Drop-out
with 35 dB atten and horns, separated by 8.0 feet
5dB/cm
Air (no snow)
+13 dBm on Sweeper
Sweeper is at 1.0 GHz
9/23/81
Horns: 1.0 → 2.4 GHz
GHz 1 2 3
1.0
2.5
HEWLETT-PACKARD 9270-1024

FIG. 3



Air Test
9/23/81
5dB/cm
33" Separation
66"
96" Separation
33"
66"
96"
Attenuation
0
10
20
30
40
50
58
55
+13 dBm on Sweeper
Sweep starts at 2.0 GHz
+16 dBm on Sweeper
Sweep starts at 6.0 GHz
GHz 1 2 3 4 5 6 7 8
Horns: 2.0 → 5.0 GHz
Horns: 4.0 → 8.4 GHz
0 1 2 3 4 5 6 7 8

FIG. 4



Dry snow test on Jan. 22, 1982
82" separation between horn faces.
5 dB/cm.
Unlevelled, Sweeper B
1
Levelled, 13 dBm Sweeper A
4
2
16 dBm
13 dBm
3
Power off
0 GHz
2
3
4
5
6
7
8

FIG. 5

Wet snow test 5/11/82

5 dB/cm 62" separation between horn surfaces

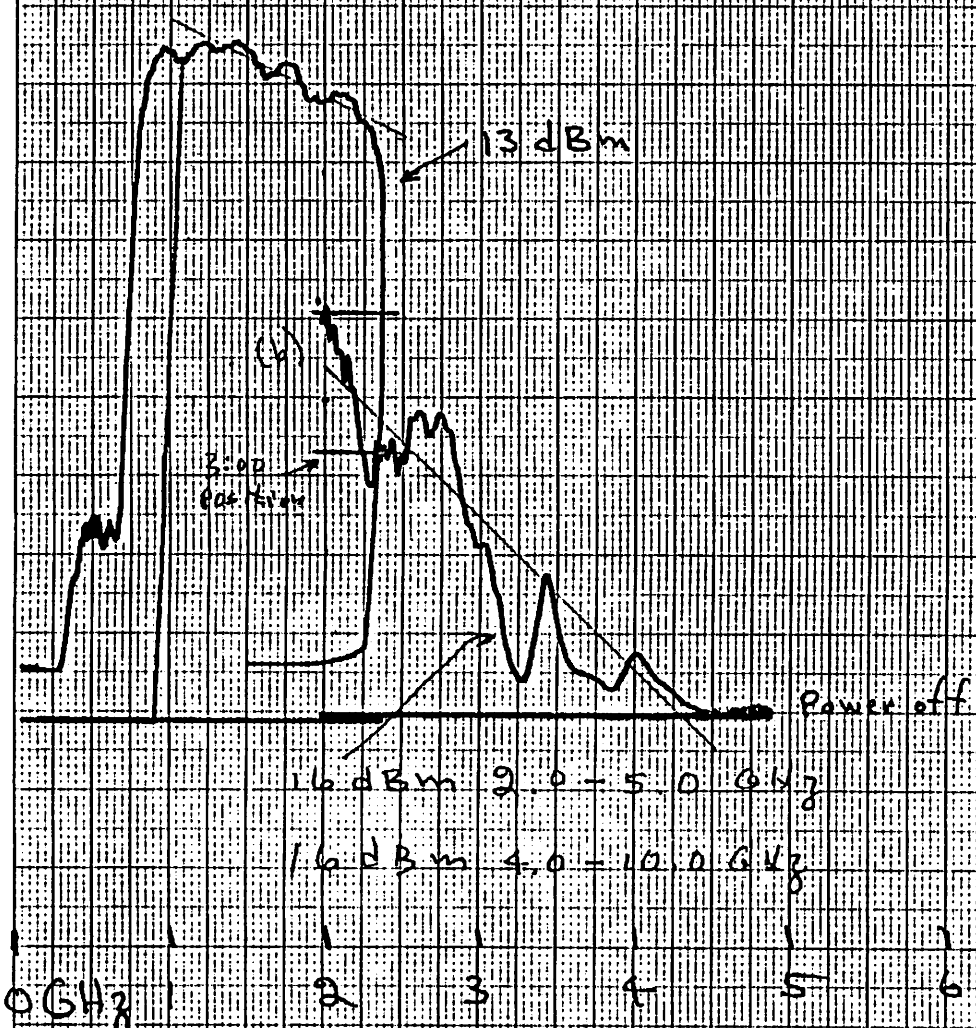


FIG. 6

TABLE I

CALIBRATION RUN IN AIR, 9/23/81, Separation = 96"

Range GHz	dBm osc.	dB Signal
1.0→2.4	13.0	39
2→5	13.0	34
4→8.4	16.0	26

TABLE II

DRY SNOW, 1/22/82, Separation = 82"

For 62" separation: Signal for

Range GHz	dBm osc.	dB Signal	Oscill. dBm = 13dBm	16dBm
1.0→2.4	13.0	43	45.4	48.4
2.0→5.0	13.0	40	42.4	45.4
4.0→7.0	16.0	37	36.4	39.4

TABLE III

WET SNOW, 5/11/82, Separation = 62"

GHz	dBm osc.	dB Signal	Dry Snow Signal	ΔdB	dB/cm
1.0	13.0	42	45.4	3.4	0.022
1.5	13.0	40	45.4	5.4	0.034
2.0	13.0	37	45.4	8.4	0.053
2.4	13.0	35	45.4	10.4	0.066
2.0	16.0	22	45.4	23.4	0.149
2.4	16.0	18	45.4	27.4	0.174
3.0	16.0	13	45.4	32.4	0.206
4.0	16.0	3	45.4	42.4	0.270
5.0	16.0	—			

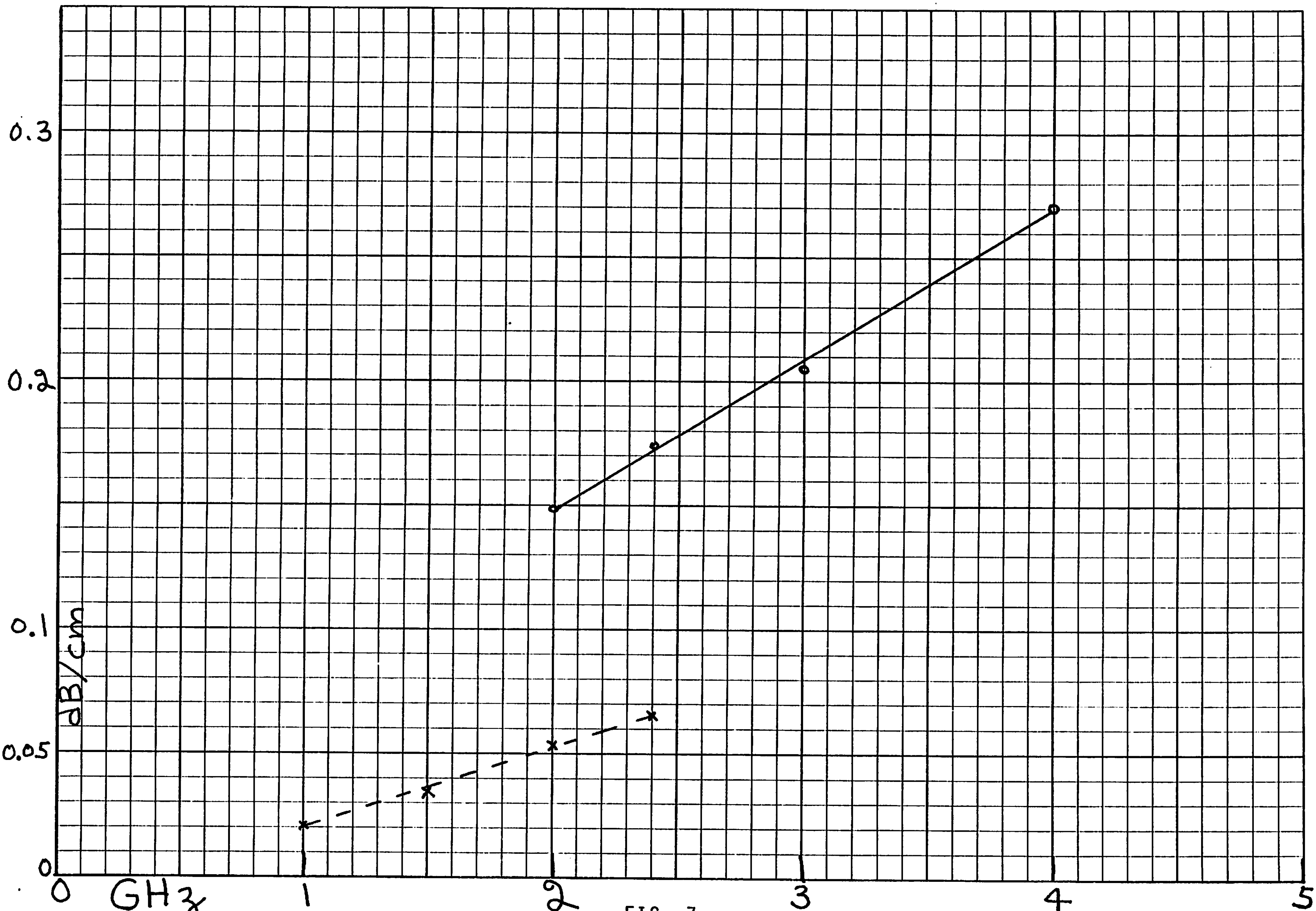


FIG. 7